A new methodology to estimate the impact of H.264 artefacts on subjective video quality

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A NEW METHODOLOGY TO ESTIMATE THE IMPACT OF H.264 ARTEFACTS ON SUBJECTIVE VIDEO QUALITY

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ABSTRACT

The impact of H.264 artefacts on subjective quality is still under investigation [1]. Contrary to existing approaches, this paper considers the impact on perceived quality of real H.264 artefacts in HDTV videos. A method for the design of spatio-temporal classification is proposed. This classification is used to locally distort sequences with the H.264 codec. Class-generated sequences are then subjectively assessed in order to evaluate the importance of each spatio-temporal class. An attempt to find a relation between local and global quality loss is then presented and discussed, along with an annoyance function model.

1. INTRODUCTION

Many studies exist concerning subjective quality assessment of coding artefacts [1, 2]. Most of them consider the influence of several coding artefacts on subjective quality. But the strongly temporal aspect of video quality assessment is often underestimated. Farias [2] synthesizes such artefacts in order to apply them independently or combined on isolated regions of the sequence. This is a content-independent approach. Wolff [1] uses sequences distorted through the use of the H.264 coding scheme. Two tasks are then asked of observers. The first is to assess the global annoyance caused by all visible impairments on the entire sequence. The second is to rate the strength of each type of artefact.

Instead of considering different artefacts, H.264 is considered here as producing artefacts (only due to quantization) that can lead to different perceived annoyance depending on the spatio-temporal class of the content. Actually, the perception of the distortions strongly depends on the local content of each distorted spatio-temporal region. For example, applying the same quantization error gives particularly visible distortions in smooth areas, whereas these distortions can be fully masked in highly textured areas. In the same way, quantization produces different results on edges. Therefore, the proposed approach is to distort only selected coherent spatio-temporal regions in terms of type of content with real coding artefacts in order to reflect common broadcasting usage. The methodology is presented in Section 2.

Then, from these partly distorted sequences, a relation between the qualities of these sequences and the global quality may be considered. It is also possible to study each class independently and to design an annoyance function for each one. Such models are detailed in Section 3.

2. THE PROPOSED APPROACH

The human visual system has different perception of impairments depending on the local spatio-temporal content where they occur. Therefore, several classes of content have been defined in order to study them separately. These are five classes defined as follows:

- smooth areas with low luminance (C_1) ;
- smooth areas with high luminance (C_2) ;
- fine textured areas (C_3) ;
- edges (C_4) ;
- strong textured areas (C_5).

Each class corresponds to a type of content with a certain spatial activity, so to a certain impact of the H.264 coding artefacts on the perceived quality. In order to obtain these spatio-temporal zones from the global sequence, a segmentation of the sequence is proposed. Then a classification of each spatio-temporal segment is processed. Distorted sequences are generated from the classification. Finally, subjective tests are designed in order to assess the impact of artefacts on subjective quality for each class.

2.1. Segmentation

From the original uncompressed sequence, the segmentation creates elementary spatio-temporal volumes. The interlaced video (1080i format) is separated into two fields. The first part of the segmentation is a block-based motion

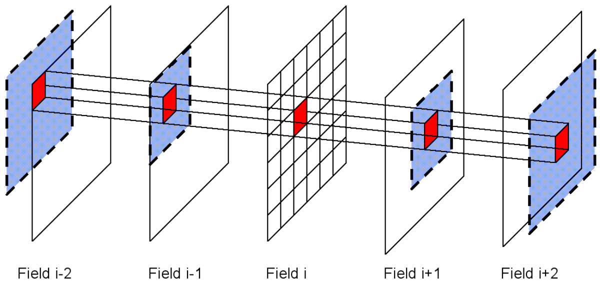


Fig. 1. Tube creation process over five fields.

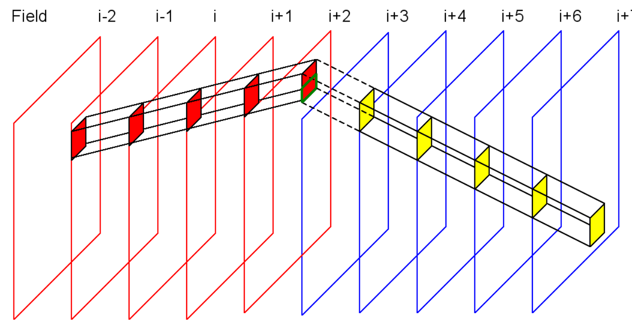


Fig. 2. Labelling of overlapping tubes.

estimation which enables the evolution of spatial blocks to be followed over time. This is performed per group of five consecutive fields of the same parity (odd and even fields). For each group of five fileds, the center field i is divided into blocks and a motion estimation of each block is computed simultaneously using the two previous fields and the two next fields as shown in Figure 1. Spatially, search windows are defined as containing the highest possible displacement in the sequence. Differences between blocks are evaluated by the mean square error (MSE) on the three YUV components. The selected motion vector is the one minimizing the MSE. The temporal tracking of each block in field i defines an elementary spatio-temporal "tube" over the five considered fields. This concept of 3D tubes has been introduced by Wolf and Pinson [3] for an objective quality video metric. In Wolf's approach, tubes are fixed in time while in the proposed approach, they are oriented along the local motion. Consequently, the temporal tubes are coherent in terms of motion and spatial activity. As HDTV content processing is of particular complexity, this motion estimation is performed on a multi-resolution representation of each field. It is first processed on the lowest resolution, then the resulting motion vector is adjusted by taking account of the next higher resolution, and so on. The three-level hierarchical process reduces significantly the required computation. The displacement vector of a frame block is the average of the two motion vectors associated with its two fields. Finally, these spatio-temporal tubes are temporally gathered to form spatio-temporal volumes along the entire sequence. This gathering consists of giving the same label to overlapping tubes as depicted in Figure 2. Some unlabelled holes may appear between tubes. They are merged with the closest existent label. Thus, every pixel of the source has one and only one label.

2.2. Classification

The second part of the segmentation is the spatial processing. It is performed as a global tracking of moving objects over the whole sequence. Tubes are merged based on their positions which overlap over time, enabling objects to be followed. This merging step is based on the class of each tube. Each set of merged tubes is also classified into a few labelled classes with homogeneous content.

This step uses four spatial gradients (ΔH, ΔV, ΔD_{45° and ΔD_{135°) computed on every pixel of each tube. Means ($\overline{\Delta H}$, $\overline{\Delta V}$, $\overline{\Delta D_{45^\circ}}$ and $\overline{\Delta D_{135^\circ}}$) over the tube of the absolute gradients are used in two spatial activity spaces $P = (\overline{\Delta H}, \overline{\Delta V})$ and $P' = (\overline{\Delta D_{45}}, \overline{\Delta D_{135}})$ in order to label the tube. Both spaces have the same geometric properties as shown in Figure 3. Plane geometry determines the global

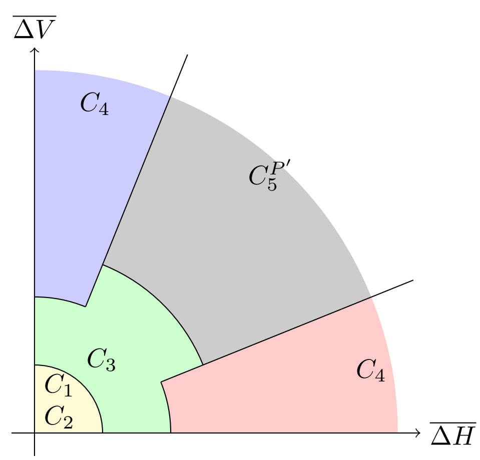


Fig. 3. $P = (\overline{\Delta H}, \overline{\Delta V})$ is the plane allowing blocks classification.

sequence block classification. Polar coordinates are used for content in order to get most relevant classification for each sequence. P' space is used only for data labelled as C_5 in P. Depending on these features, a tube may be labeled as corresponding to a smooth area (C_1 or C_2 in both planes), a fine textured area (C_3 in both planes), a strong textured area (C_5 only in P') or an edge (C_4 in both planes). No directional information is conserved about the edges. Artefact visibility in smooth areas depends on the luminance level. Therefore, two different labels have been defined: smooth areas with

Sequence	HDTV Bitrates
(a) Above Marathon	5 ; 8 ; 10
(b) Captain	1 ; 3 ; 5
(c) Dance in the Woods	3 ; 5 ; 6
(d) Duck Fly	4 ; 6 ; 8
(e) Fountain Man	1 ; 5
(f) Group Disorder	2 ; 4
(g) Rendezvous	6 ; 8
(h) Ulriksdals	1 ; 4

Table 1. Chosen bitrates (in Mbps) per video sequence.

low luminance (C_1) and smooth areas with medium or high luminance (C_2). A threshold is defined to distinguish them. Finally, five labels are used to classify every merged tube in every sequence.

2.3. Sequences generation

Distorted sequences are generated from the original HDTV sequence, the H.264-distorted sequences at several bitrates and the classification of the original sequence. H.264 coding is performed with the H.264 reference software [4] at High Profile. Several bitrates of H.264-distorted sequences are selected in order to cover a significant range of quality. Bitrates (in Mbps) used for each sequence are presented in Table 1. Original uncompressed sequences were provided by the swedish television broadcaster SVT. Figure 4 presents an example of each of the eight sequences provided.

Precautions have been taken in the coding, especially for the rate control aspect which is particularly critical in the reference software. Parts of the distorted sequence corresponding to a class are inserted in the original sequence. This process creates one sequence per class with one spatio-temporal homogeneous content part distorted. Steps are shown in Figure 5 (here with only the quarter of an actual HDTV image). This figure does not reflect the temporal aspect of the segmentation. The classification frame (b) shows the different classes. Luminance value Y of a pixel in this image is obtained by: $Y = i \times 30$ with i the index of the class. Class C_1 is distorted in the last image (c). It is visible on the tree in the middle of the frame. Borders between original and distorted regions are treated so as to smooth the transitions.

2.4. Subjective quality assessment

Subjective quality assessment tests are designed to individually measure the impact of each class on the perceived quality. According to international recommandations [5] for the test conditions, assessments are performed using the SAMVIQ protocol [6] with at least 15 validated observers

(a) Above Marathon

(b) Captain

(c) Dance in the Woods

(d) Duck Fly

(e) Fountain Man

(f) Group Disorder

(g) Rendezvous

(h) Ulriksdals

Fig. 4. Examples of the SVT HDTV sequences.

and normalized viewing conditions. The monitor used is a 1920×1080 HDTV 37PF9731D/10 Philips LCD display. Uncompressed 1080i HDTV sequences are played with a Doremi V1-UHD player. The test session for one content at bitrate B is composed of the following sequences:

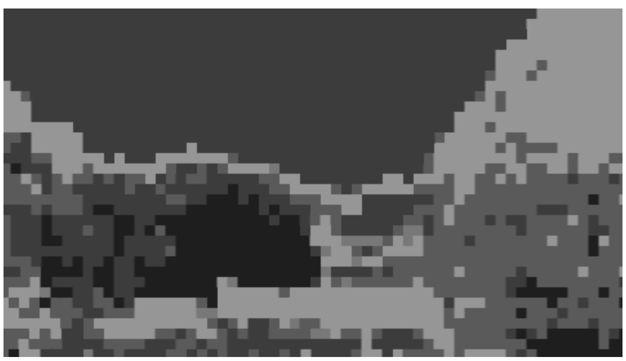
1. explicit reference (high anchor) ;
2. C1-only distorted sequence at B ;
3. C2-only distorted sequence at B ;
4. C3-only distorted sequence at B ;
5. C4-only distorted sequence at B ;
6. C5-only distorted sequence at B ;
7. entirely distorted sequence at B ;
8. entirely distorted sequence at a low bitrate (low anchor) ;

9. entirely distorted sequence at a third bitrate, corresponding to a quality of 40 or 60 (on a 100 scale), it is defined depending on B and on the low anchor bitrate ;

10. hidden reference (high anchor).

High and low anchors are used in the SAMVIQ protocol to indicate to the observers what the limits of the quality scale are. The explicit and hidden references are the same uncompressed version of the sequence. The explicit reference is clearly labeled as the reference for the observer, while the other sequences are not labeled.

(a) Original frame.



(b) Classification of the frame.

(c) Distorted frame (class C_1 only).

Fig. 5. Steps of the distorted sequences creation.

3. RESULTS AND MODELING

3.1. Segmentation statistics

Each tube category corresponds to a certain proportion in the sequence. Such proportions are computed as the ratio between the number of pixels in the C_i class and the total number of pixels of the sequence. The mean proportions of each class in the sequences are presented in Table 2 (in percentages).

Sequence	C_1	C_2	C_3	C_4	C_5
(a)	3.75	17.45	27.79	0.94	50.06
(b)	13.14	78.26	6.81	1.43	0.36
(c)	3.80	22.57	53.85	3.02	16.75
(d)	0.13	8.97	19.50	10.70	60.70
(e)	10.52	70.71	13.37	1.45	3.93
(f)	25.28	38.58	29.80	1.79	4.54
(g)	8.78	12.38	19.87	2.05	56.92
(h)	13.54	41.31	40.48	1.36	3.30

Table 2. Proportions of each class of every sequence (in %). Labels of the sequences are from Figure 4.

Class C_1 (smooth areas with low luminance) has a moderate range of values, from almost zero (0.13%) to a quarter of the image. Class C_2 (smooth areas with high luminance) has the highest range of proportions. Sequences with the waterfall (Captain and Fountain Man) have particularly high proportions due to classification in C_2 of the zones where water is falling. Class C_3 (fine textured areas) has a strong importance, between 6 and 54%. Class C_4 (edges) has particularly low importance. Except for one sequence at 10%, its proportion is less or equal to 3%. Finally, class C_5 has a high range of values, from almost zero (0.36%) to more than 60%.

These proportions are consistent with the nature of the sequences. These are all made of realistic contents with outdoor scenes. Therefore, few edges, some smooth areas (like clothes or the sky) and a lot of textures (trees and grass) are present.

3.2. Relation between local ΔMOS and global DMOS

A Mean Opinion Score, denoted MOS(C_i, S_j, B_k), is obtained for each partly distorted sequence S_j and for each class C_i at each bitrate B_k. The difference between this partial MOS and the MOS of the original sequence (hidden reference) is called ΔMOS(C_i, S_j, B_k). It indicates the quality loss induced by the distortions in class C_i. Each distorted class induces a quality loss which is part of the global quality loss of the entirely distorted version compared to the original one.

As an attempt to determine a relation between the local ΔMOS of the classes and the global DMOS, an additive model has been tested. Such a relation would be very useful in order to design an objective quality metric using the presented methodology. Such a metric would evaluate the global quality from classes quality. The tested relation uses the sum of the ΔMOS of some or all the classes, without any weights. Table 3 presents the combinations and the associated CC and RMSE. For CC < 0.9, only combinations with one class have been kept.

Combination	CC	RMSE
$C_2 + C_4 + C_5$	0.9485	14.51
$C_2 + C_5$	0.9440	12.55
$C_2 + C_3 + C_4$	0.9094	21.52
$C_1 + C_2 + C_3 + C_4 + C_5$	0.9058	67.16
$C_1 + C_2 + C_4 + C_5$	0.9052	35.42
$C_2 + C_3 + C_4 + C_5$	0.9041	44.53
...	...	...
C_2	0.7664	22.40
C_3	0.7094	28.54
C_5	0.6400	35.80
C_4	0.5472	54.64
C_1	0.5349	36.42

Table 3. Combinations of classes ΔMOS and their respective correlation coefficients and RMSE with DMOS.

These combination results reveal the relative importance of each class in the merging process made by the mean observer. Both combinations with a CC over 0.94 and the lowest RMSE use almost exclusively the classes C_2 and C_5. Therefore, those two are particularly important in the merging process. Despite its low proportions and single combination correlation (0.5472), the class C_4 is present in five of the six first combinations. The distortions on these three classes (one with edges, one with smooth areas and one with textures) are closely related to the global quality of the sequence. At the bottom of the table, single class combinations provide the lowest correlations and the highest errors, revealing that using only one class is not sufficient to explain the global behaviour. Furthermore, these values confirm the high importance of the class C_2 with the highest CC for a single combination (0.7664) and the low importance of C_1 and C_4 alone. The latter tend to be of importance only combined with other classes.

Despite its simplicity, such an approach provides high correlations with very few strategic classes. Therefore, it is possible to envisage a pooling of the partial qualities of the classes into a global one for the sequence. However, errors are quite high, revealing the poor precision of the relation. Moreover, it does not take in account the proportions of the classes used in the combinations. If a class has low proportions (like C_4), it cannot reflect the global loss of quality. On the other hand, class C_1 has moderate proportions and very low importance here.

3.3. Model of annoyance function

In her approach, Farias is able to get an annoyance function depending on the strength of her synthesized distortions parameters. But here, no control is possible on the distortion level of a class with the only use of the H.264 coding parameters. Actually, several effects are part of the quality loss induced by the distortions in one single class C_i. First are the distortions in themselves. They correspond to a certain quantization step in H.264, therefore to a certain bitrate. However, due to the high number of observers required to assess the sequences, only few bitrates are available. Moreover, when only a spatial part of the sequence is distorted, obtaining the same quality required a lower bitrate than when the whole sequence is distorted. Therefore, bitrates could reach very low level, without being realistic in a broadcasting context. Finally, the bitrate is applied by the coder to the entire sequence, not only to a specific class. But the spatial repartition of the bitrate is not homogeneous. Therefore, the bitrate is not a sufficient measure of the distorsions. These are the reason why the Mean Square Error (MSE) between the original and distorted versions of the sequence has been used in order to evaluate the distortions. Distortions also depend on the amount of movement in the class. Indeed, the more movement there is, the higher the motion vectors are, therefore the greater the bitrate they require. Distortions are hence characterized both by the MSE and the mean movement of the class. Motion vectors are obtained from the motion estimation step. The proportion of the class area among the whole sequence inferes also in the mean observer's judgment construction. Effectively, the bigger the class, the more visible, therefore the more probable of being annoying it is for the observers. Finally, the impact of a distorted part depends also on its spatial localisation along the sequence. An artefact situated in the center of the screen is noticeably more attractive than the same in a corner. However, this effect is not considered in the scope of this study.

An annoyance function has to take into account such effects. As a first attempt to model the annoyance function

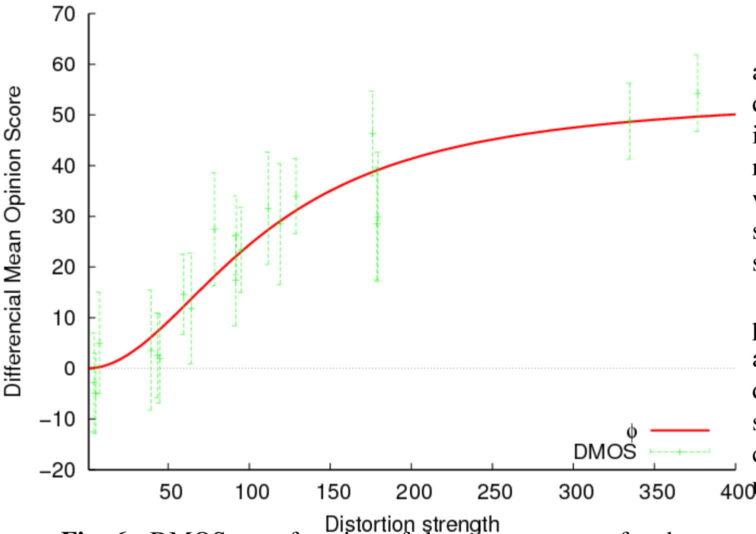


Fig. 6. DMOS as a function of the error measure for the class C_1.

of each class, a weight of the mean error of the sequence is used for the class C_1:

$$f(M, P, E) = (1 - \frac{M}{M_T}) \times P \times E \qquad (1)$$

with M_T a parameter to determine, M the mean movement, P the mean proportion and E the MSE of the sequence. The factor $1 - \frac{M}{M_T}$ describes the influence of the movement on the error perception. The more movement there is in the smooth areas of the sequence, the more masking of the errors occurs. Therefore, the increased movement decreases the impact of the error.

Figure 6 depicts the DMOS of the sequences as a function of the computed error. Intervals of confidence at 95% of the DMOS are also plotted. The psychometric function corresponding to this model is:

$$\phi(e) = \frac{a \times e^b}{c + e^b} \qquad (2)$$

with e the error, $a = 53.97$, $b = 1.996$ and $c = 11918$ the parameters of the model. This function is also plotted in Figure 6. The parameter M_T is here taken equal to 40 pixels per image or 500 pixels per second. The correlation between the model and the values obtained from the subjective tests is equal to 0.9514. The RMSE is equal to 5.25. This model is therefore a good predictor of the loss of quality induced by the class C_1.

4. CONCLUSION

This paper proposed a new manner to estimate the impact of H.264 artefacts on subjective video quality. A segmentation that creates spatio-temporal volumes with respect to a defined content typology has been detailed. Each spatio-temporal volume has been distorted with real artefacts and assessed independently. Therefore, to predict the global quality of a sequence, the presented methodology separates it into several content-based classes. It is then possible to relate the impact of each of these classes on visual quality with the global quality of the distorted sequence. At the same time, a model of annoyance function has been presented for the class C_1.

This content-based impairment measurement can be applied in both quality metric and coding domains. For example, it can be used in the design of an objective video quality criterion to weight the impact of artefacts with respect to the local content. In a coding context, the impact of coding artefacts in a certain part of the sequence can also be used to determine a more effective rate allocation.

5. ACKNOWLEDGEMENT

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